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Using Landscape History and Baseline Data in the Restoration of a Midwestern Savanna

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Over one hundred and fifty years of Euro-American settlement has dramatically altered Midwestern landscapes, resulting in the widespread conversion of native habitat. Numerous opportunities to conduct ecological restoration exist within the Midwest, with the potential to increase habitat and landscape heterogeneity, secure critical ecosystem services, and provide opportunities for research and education. Site history is an important consideration for most restoration projects, and multiple sources of historical data may be required to unravel the complicated history of intensively used Midwestern landscapes. The collection of baseline data is another significant component of most restoration projects, allowing for an evaluation of community responses to restoration treatments. Here we integrate a variety of historical data sources in a GIS environment, including data derived from the original Public Land Survey of Iowa, maps from historic state atlases, aerial photography, and informal interviews to develop a landscape history (1840–2004) of a prairie-savanna complex undergoing restoration in central Iowa. Furthermore, we collect baseline data relative to the present-day state of the on-site floral and faunal communities. Analysis of landscape history suggests that the study site represents a remnant bur oak savanna that has undergone significant changes in response to fire-suppression and to removal of grazing livestock. Baseline data was collected on the distribution and abundance of bur oaks, a defining savanna species, and revealed a flourishing population across multiple size classes. Both field and observational data on the on-site mammal community reveal the presence of numerous mammal species ranging widely in morphology, diet, and behavior. Continuing restoration of the study site will be informed by the landscape history developed in this study, as well as by the baseline data that was collected.

INDEX DESCRIPTORS: Midwestern landscapes, oak savannas, historical data, GIS, ecological restoration.

There is an approximately 170 year history of anthropogenic land-use by Euro-Americans in the Midwestern United States, during which the vast majority of native habitats (primarily prairies, forests, savannas, and wetlands) have been converted into fields for crops, pastures for livestock, and homesites for settlers (Farrar 1981, Thompson 1992, Burkart et al. 1994, Turner and Rabalais 2003). This legacy of land-use change, as well as the concomitant changes in land cover and other landscape features (such as terrain, drainage, and soil characteristics), persists in the modern landscape and has significant consequences for ecosystem functioning and natural resource management (Anderson et al. 1996). The widespread conversion of native habitat in the Midwest has been linked to declines in floral and faunal populations (Farrar 1981), as well as reduction in water quality at the state and regional scales (Burkart et al. 1994, Rabalais et al. 2002a, 2002b)

In states such as Iowa, less than 10% of the native habitat remains (Farrar 1981); the few prairies, forests, savannas and wetlands that do persist in Iowa landscapes are often degraded, relative to species diversity, community composition, and ecosystem services. In many instances, anthropogenic processes have pushed these remnant communities across system thresholds and onto trajectories of change leading to towards radically different communities. For example, the reduction and/or elimination of the fire-regime within Midwestern oak savannas since the time of settlement by Euro-Americans contributed significantly to the rapid encroachment of shade-tolerant, woody vegetation, which in turn has prevented the recruitment of relatively shade-intolerant, native tree species such as bur oak (*Quercus marcrocarpa* Michx) (Curtis 1959, Grimm 1981). Ecological restoration has become an increasingly popular management option in Iowa and other Midwestern states, in recognition of the widespread loss of habitat (Farrar 1981, Thompson 1992, Burkart et al. 1994). There is significant potential for restored habitats to provide critical habitat for flora and fauna, as well as to provide valuable ecosystem services (such as the mediation of agricultural runoff).

In a region so transformed by anthropogenic land-use, however, the landscape history of a site targeted for restoration can have significant effects on the restoration process for at least two important reasons. First, as noted above, the land-use legacy of a site may have persistent effects on current and future ecosystem properties. For example, many highly productive agricultural fields in the Midwest were formerly diverse, tall-grass prairie communities; a generation or more of plowing, fertilizer and pesticide addition, and erosion by wind and water have in many instances radically altered soil characteristics – an important planning consideration in conservation or restoration planning. Foster et al. (2003) identified a list of soil attributes affected by a legacy of agricultural land-use, including the homogenization of soil through plowing, the depletion of soil nutrients, and alteration of the soil-based microbial community. Second, the landscape history of the site targeted for restoration can be an important consideration in the restoration

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planning process. A common goal of restoration projects is to return a site to some previous, historical state, or at least to establish a trajectory of change on the site that will lead to such a result. Such a goal requires knowledge of site history prior to conversion or degradation. Site history can also guide the collection of baseline data, by which the effectiveness of restoration treatments may be evaluated. For example, knowledge that a site was formerly a tallgrass-prairie might prompt vegetation surveys at the beginning of the restoration process, so that the response of the floral community to continued restoration could be evaluated.

In much of the Midwestern U.S., more than a century and a half of intensive anthropogenic land-use had produced a complicated legacy of landscape change. Understanding the causes and consequences of changing landscapes in the region may require analysis of multiple forms of historic data to understand, since no one no data source spans the century and a half since settlement. Such data (such as aerial photography, maps, survey records, and settler accounts) may be hard to integrate effectively in an analysis framework, as different forms of historic data have limitations in terms of resolution, scale, extent, availability, and quality (Egan and Howell 2001). In order to develop a coherent history for Midwestern landscapes, disparate forms of historic data must be integrated together effectively, taking into account the limitations associated with each data type. Landscape histories that emerge from such analysis have the potential to not only inform ecological restoration, but also to guide natural resource management and planning in a region where many ecological systems are critically imperiled as a result of anthropogenic land-use.

We integrated historical data from a variety of sources in order to investigate the landscape history (~1840–2004) of a site undergoing restoration in central Iowa. We link our results to the ongoing restoration process, make our best guess as to the pre-settlement state of the site, and comment on how our results can inform future restoration activities. On the same site, we also collected baseline data on components of the floral and faunal community to facilitate comparative study in the future as restoration of the site continues. Based on these data, we discuss some present-day characteristics of the site relevant to the restoration process. We also highlight opportunities for environmental education and student-led research related to the restoration process.

STUDY SITE

The Elwood prairie and savanna restoration site (~9.5 ha) lies within the city of Ames (Story County) in central Iowa, and is adjacent to Iowa State University (Fig. 1). The site is currently designated as an Iowa State University Outdoor Teaching Laboratory, and is managed by the Iowa State University Outdoor Teaching Lab Committee. The soils on the site are coarse-loamy, moderately well drained, and are classified as Hanlon-Spillville soils in the Iowa Soil Properties and Interpretations Database (ISPAID 2004). The site occurs on a floodplain, which experiences rare instances of inundation and was last flooded in 1993.

Approximately 7 ha of the site is successional forest, and is currently not under management. The remainder of the site (~2.5 ha) is being restored as a oak savanna; the northern two-thirds of this portion of the site is open, with a plant community composed primarily of native and exotic grasses and forbs (including Little bluestem, *Schizachyrium scoparium* (Michx.) Nash, and Indian grass, *Sorghastrum nutans* (L.) Nash). The southern third contains large, overstory trees with broadly spreading canopies (primarily bur oak; *Quercus macrocarpa* Michx) in addition to an understory layer composed of a combination of native and exotic grasses, forbs, and woody species. The presence of mature, overstory bur oaks suggests that the site may represent a remnant oak savanna, an extremely rare habitat type in the Midwestern United States (Nuzzo 1986, Johnson et al. 2002). Invasive species present on-site include common buckthorn (*Rhamnus cathartica* L.), Tartarian honeysuckle (*Lonicera tatarica* L.), Canadian thistle (*Cirsium arvense* (L.) Scop.), and Reed canary grass (*Phalaris arundinacea* L.).

Prior to the initiation of restoration activities, a limited landscape history of the site was known; after being used as a

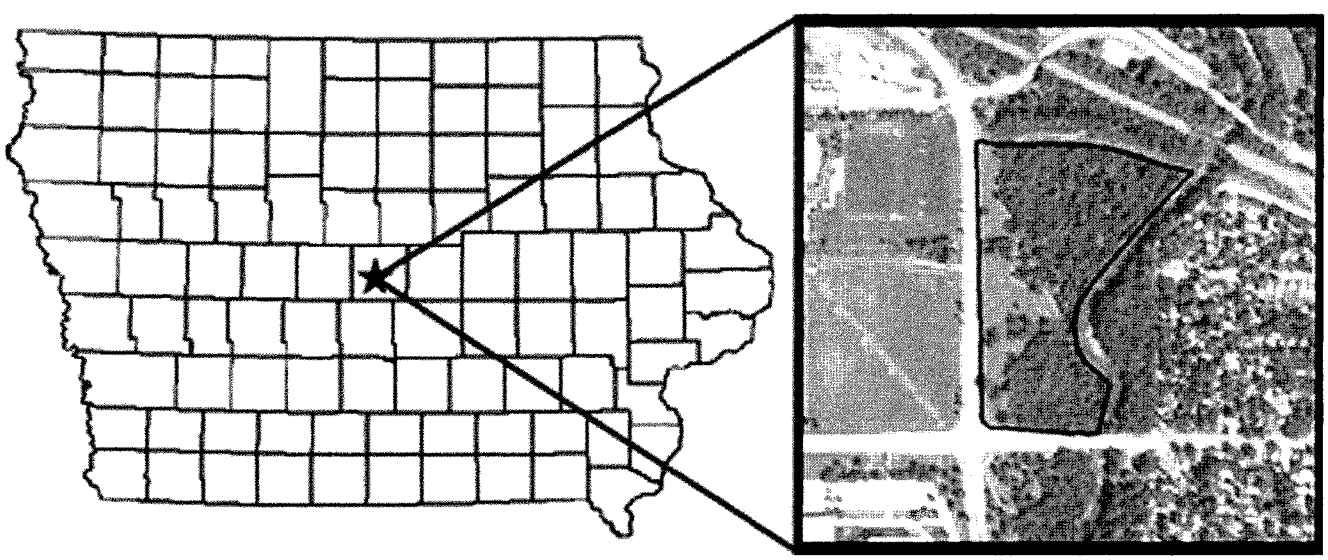

Fig. 1. Location of the Elwood prairie and savanna restoration site in Story County, IA. The approximate site boundary has been superimposed over a 2004 aerial photo of the site.

horse pasture in recent decades, active management of the site ceased and woody vegetation was allowed to encroach (Pease pers. comm.). Restoration efforts began in earnest on the site in the summer of 2000. Since the site contained elements of Midwestern savanna habitats (such as native prairie grasses and forbs, and mature bur oak trees), the goal of the restoration was, and continues to be, a bur oak savanna community. Restoration efforts have included: removal of shade-tolerant woody vegetation (such as green ash, *Fraxinus pennsylvanica* Marsh., buckthorn, and honeysuckle), application of glyphosate, control of invasive species, reintroduction of a controlled burning regime, and native seed addition in the form of a locally collected, 50-species mix of native grasses and forbs. No specific treatment structure was used (in terms of applying specific combinations of restoration treatments to different portions of the site in order to form an experimental design). Community involvement has played a critical role in the restoration process with over 400 students and other community members participating in the restoration, and the site is often visited by students of all ages on field trips or as a part of outdoor learning activities (Pease pers. comm.). Site management includes periodic controlled burns, native seed and plant additions, removal of woody vegetation, and control of invasive species.

OBJECTIVES

We had three specific objectives for this research, with the overarching goal of informing continued restoration activities on the site as well as providing opportunities for future research and education related to the restoration process.

First, we wanted to incorporate multiple types of historic data in order to develop a more detailed landscape history for the site than was known at the time restoration activities were initiated. As previously noted, the landscape history associated with a site may have important effects on the restoration process. More specifically, we wanted to develop a) an informed description of the condition of the site at or around the time of settlement of the region by Euro-Americans (early to mid-1800s) and b.) an understanding of the trajectory and magnitude of landscape change that has occurred on the site over the last 150+ years. We tailored our research to inform future restoration activities on the site; e.g., evidence that the site is a remnant oak savanna might suggest that restoration activities focus on maintaining a bur oak population, as well as a grass-dominated understory plant community. Conversely, if a different landscape history for the site emerged from the research (a tall-grass prairie lacking trees, for example, or a dense forest), then the results might suggest alternative restoration trajectories.

Our second objective was to collect baseline ecological data on floral and faunal components of the site, in order to a.) provide a means for the assessment of the effect of continued restoration and to inform future management of the site, and b.) facilitate future research on the site, especially research involving students from the Department of Natural Resource Ecology and Management at Iowa State University. We collected data on a.) the abundance, size and spatial distribution of bur oaks (the dominant overstory tree on the site) across seedling, sapling, and tree size classes, and b.) the composition of the on-site mammal community, using a combination of field-collected and observational data.

Bur oak is a large, picturesque tree species with deeply furrowed bark, extensive root systems, and stout, spreading canopy branches (van der Linden and Farrar 1993). Native to Iowa and other Midwestern states, bur oak was historically a dominant overstory tree in mesic-loamy (tallgrass) and floodplain savannas (Nuzzo 1986, Haney and Apfelbaum 1993, Anderson 1998). Bur oak is a slow-growing species, with growth rates in Iowa ranging between 0.09 m and 0.52 m/yr in height and between 2.5 mm and 6.4 mm/yr in diameter (Johnson 1990). Bur oaks are relatively long-lived, sometimes reaching ages of 300–350 years or more (Johnson 1990, Johnson et al. 2002). Possessing thick, fire-resistant bark, bur oaks often persisted in savanna environments as a result of understory fires which removed other woody vegetation (Nuzzo 1986, van der Linden and Farrar 1993). The regeneration of bur oaks, along with other *Quercus* species, is an important conservation issue at the state, regional, and national level (Lorimer 2003, Brudvig and Asbjornsen 2005). We had *a priori* knowledge of mature bur oak trees on the site; however, we were uncertain how many bur oaks of other size and/or age classes were present. If few juvenile oaks were present, then it would suggest that the oak population on the site would not persist in the future without direct intervention (i.e., seeding or planting, potentially combined with altered fire regimes). A more diverse bur oak population (composed of trees from different age/size classes, especially younger trees) might suggest less focus on oak restoration, and more effort spent on understory species. The spatial distribution of oaks on-site was also of interest, since native oak savannas have widely spaced overstory trees relative to smaller size classes. It was supposed that analysis of the spatial pattern of oaks might inform restoration efforts, as well as provide baseline data for future studies of the spatial distribution of oaks on the site.

Baseline data was also acquired in relation to the on-site mammal community, an important component to native Midwestern communities. Through actions such as herbivory, frugivory, seed dispersal, and nutrient cycling, mammals such as deer, rabbits, mice, and squirrels can have significant effects on community structure in prairies (Olff and Richie 1998) and savannas (Deitschmann 1965, Johnson et al. 2002). Additionally, changes in the mammal community on the site in response to future restoration are of interest to restoration planners (Pease pers. comm.). Finally, mammal surveys are useful additions to outdoor laboratories and interesting educational experiences for students (i.e., catching and identifying small mammals, locating and discussion mammal burrows or tracks).

Our final objective was to show that the continued restoration of the site could serve as an effective framework for both research and education. Numerous authors have highlighted the usefulness of restoration projects as ongoing research projects, as well as interactive learning tools for students of all ages (see Discussion). Here, we focus on opportunities for student-initiated ecological research (undergraduate and graduate) on the site, as well as the continued use of the site as an education showcase for students of all ages.

METHODS

Landscape history

A variety of historical data were utilized in order to determine both the landscape history of the site, including survey records, atlas maps, aerial photography, and informal interviews. The earliest spatially explicit record of Iowa vegetation has been derived from notes from surveyors conducting the Public Land Survey (PLS) of Iowa from 1832–1859. In an attempt to provide a means for accurately recording and relocating survey points, tree species, size, and location were recorded at each point along section lines throughout the state (Stewart 1935, Schulte and Mladenoff 2001). PLS survey records have been compiled and digitized into GIS-compatible vegetation layers for each county in Iowa (Anderson et al. 1996). While there are limitations to these data in terms of resolution, accuracy, and interpretation (Bourdo 1956, Schulte and Mladenoff 2001, Mladenoff et al. 2002), PLS-derived data are of sufficient spatial quality at the landscape scale to have been used successfully in prior studies of landscape change (Almendinger 1997, Radeloff et al. 1999, Schulte and Mladenoff 2001). A GIS layer of GLO township maps for Story county (1847) was obtained from the Iowa Department of Natural Resources and visualized in ArcGIS 9.1 (ESRI 2004) (Fig. 2). We then examined the historic vegetation (1847) at the present location of the study site.

Historic state atlases also provide a snapshot of some components of the historical vegetation of Iowa, as maps showing the presence or absence of 'timber' were recorded for each county in at least two atlases (Fig. 2). Digital maps of Story County were produced from the *Illustrated Historical Atlas of the State of Iowa* (Andreas 1875) and from the *Huebinger State Atlas of the State of Iowa* (Huebinger 1904), and were similar in appearance and resolution. Although the specific methodology used by the atlas mapmakers to spatially locate various landscape elements is unknown, W. J. Petersen noted in the introduction to the 1970 reprint of the Andreas atlas that extant maps or surveys may have been compiled to some degree (IAGenWeb 2005). We followed other authors in assuming that the 'timber' map element could serve as a surrogate for forest cover (Kupfer and Malanson 1993, Poole and Downing 2004). The present location of the study site was then examined on each county map to determine whether or not forests were historically recorded as being present.

The third type of data utilized were historic aerial photographs of Story County, which are available at ~20 year-intervals from 1940 to 2004. Photos of the site from 1939, 1958, 1980, and 2004 were acquired from the collection at the University of Iowa Library, scanned at 600 dpi, georectified, and visualized in ArcGIS. Land-cover on the site (1939–2004) was then captured by digitizing discrete vegetation patches on the site as one of two cover classes, grass or forest, based on presence or absence of tree cover. At each time-step, landscape metrics (number of patches, total patch area, mean patch area) were calculated for both cover classes using the VLATE 1.1 extension for ArcGIS (Lang and Tiede 2003). Digital cover maps were also created, showing patch distribution for each time-step.

Historical data derived from these sources were supplemented with interviews of Iowa State University faculty and staff with knowledge of site history. Data derived from the PLS vegetation layer, the historic state atlases, and from the informal interviews were not of sufficient resolution and accuracy to warrant patch-level analysis, and were used qualitatively in combination with quantitative data derived from aerial photography to develop a landscape history for the site from ~1847–2004.

Baseline ecological data

Over a period of several weeks in August and September of 2005, bur oak seedlings (<2.5 cm dbh), saplings (2.5 cm–12.7 cm dbh), and trees (>12.7 cm dbh) were surveyed on the managed portion of the site, in such a way that facilitated future studies of oak dynamics in response to restoration. Regardless of size class, each oak located was measured (dbh), tagged, and spatially referenced with a GPS unit (n=179). GPS coordinates of each seedling, sapling, and trees were converted to point shapefiles in ArcView 3.3 (ESRI 2002) and merged in ArcGIS to form a single layer of coordinate points. Digital maps were created in ArcGIS showing the distribution of oak seedlings, saplings, and trees. In order to assess the spatial distribution of bur oaks on the site, the mean nearest neighbor distance was calculated for each size class using Hawth's Tools extension for ArcGIS (Beyer 2004).

We sought to describe the on-site mammal community using a combination of observational data and data obtained from a small mammal survey conducted over two consecutive days in October 2005 by an undergraduate mammalogy class. Sampling was done using 50 Sherman live traps distributed in five line-transects throughout the managed portion of the site. Under the guidance of the professor, students were involved in the baiting, distribution, and collection of traps, as well as the capture and identification of small mammals. Presence/absence data from the small mammal survey were combined with observational data (sightings, sign) on other mammals present on the site in order to develop a more detailed, albeit incomplete, description of the mammal community at this stage of the restoration process.

RESULTS

Landscape history

In the process of developing a landscape history for the study site, our research revealed that significant changes have

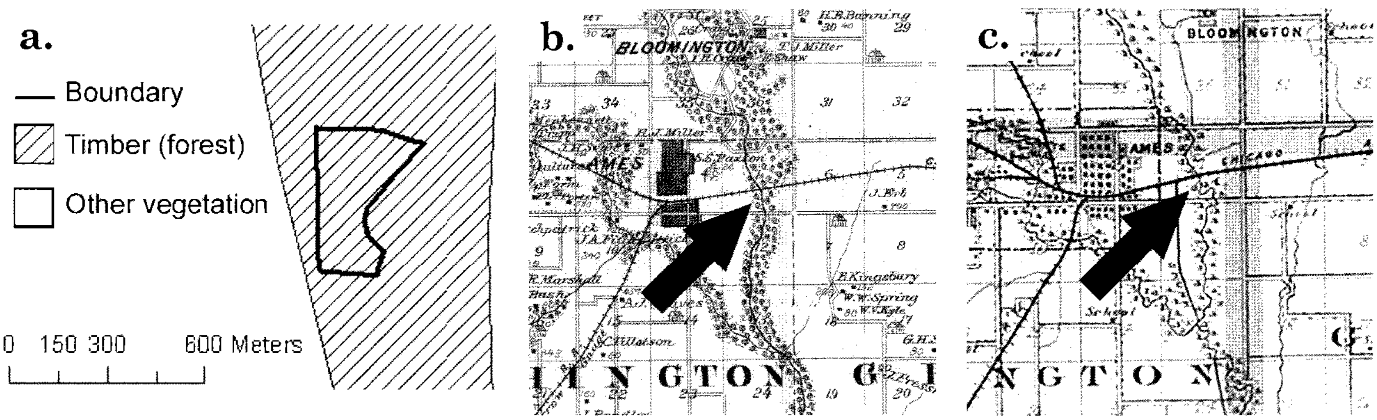

Fig. 2. Historic vegetation associated with the present-day location of the study site: a.) PLS-derived historic vegetation layer (1847) for Story County (IA) with site boundaries superimposed; b.) Location of site on county map from *Illustrated Historical Atlas of the State of Iowa* (Andreas 1875); c.) Location of site on county map from *Huebinger State Atlas of the State of Iowa* (Huebinger 1904).

taken place since the mid-1800s. Some components of land-cover, however, have remained relatively consistent over the last 150 years. Evidence from multiple data sources suggests that the site has been forested to some degree since at least the mid-1800s. Analysis of the PLS-derived vegetation layer for Story County (1847) indicated that early surveyors recorded an area encompassing the site as having forest cover, one of thirty-eight vegetation types were identified by Anderson (1996) in the original survey notes for Iowa. The maps of Story County taken from the 1875 and 1904 Iowa State Atlases also indicate the presence of trees on the site (Fig. 2). Large, overstory trees were also present on the site in all four photo time periods (1939, 1958, 1980, 2004), as well as larger patches of forest.

From 1939–2004, however, analysis of aerial photography revealed substantial changes in patch number, mean patch area, and total class area. Two distinct phases of landscape change were observed (1939–1980, and 1980–2004). From 1939–1980, the total number of patches increased from 38 to 43. The number of closed patches increased from 19 to 30, while the number of open patches decreased from 19 to 13. Total closed area and the mean area of closed patches declined during the same time period, while total open area and mean open patch area increased (Table 1). The percentage of the site under tree canopy declined from 62.4% in 1939 to 49.7% in 1980. From 1980 to 2004, the total number of patches declined dramatically, from 43 in 1980 to 7 in 2004. The number of closed patches decreased from 30 to 3, while the number of open patches decreased from 13 to 4. Total closed area increased by nearly 30,000 m^2, while the mean area of closed patches increased by approximately 23,000 m^2. Concomitantly, the percentage of the site under tree canopy increased by 30%, to 79.7%. Total open area declined by approx. 28,000 m^2, while the mean area of open patches increased by over 1,000 m^2. Overall, closed cover increased from 1939–2004, and the total number of discrete patches on the site declined dramatically. Digital maps of land-cover illustrate both the increase in tree cover and the decrease in total patch number from 1939–2004 (Fig. 3).

The specific land-use of the site is unclear prior to approximately 1940. No evidence of a specific land-use was observed from the aerial photography of the site in 1937, and neither the atlas maps nor the PLS survey records provided relevant information. Based on informal interviews of Iowa State University faculty and staff, the site was used as a horse pasture from ~1940 (and perhaps earlier) until 1989 (Kaiser, pers. comm., Miller, pers. comm.). From 1989 to 2000, the site was not associated with any specific land-use. In addition to the current use of the site by Iowa State University as an ongoing restoration project, the City of Ames constructed a running and biking trail through the site in 2001 in conjunction with the initiation of the restoration project.

Bur oak survey

A total of 179 bur oak seedlings, saplings, and trees were measured and recorded in the course of the study (seedling n = 143, mean dbh < 2.5 cm; sapling n = 31, mean dbh = 6.7 cm; tree n = 5, mean dbh = 78.0 cm). A distribution map was created to display the distribution of bur oak individuals based on size class (Fig. 3). The largest oak present was 124.0 cm in diameter; using published growth rates for bur oaks in Iowa (Johnson 1990), the age of this tree was estimated to be between 100–200 years old. The second largest oak on the site was 106.9 cm in diameter, and was also estimated to be over 100 years in age. These results are consistant with Apfelbaum and Haney (1991) who found dominant oaks in Midwestern savanna remnants to be between 80–250 years old.

A somewhat clustered distribution of oaks is evident from the distribution map (Fig. 3); clustering is especially evident in sapling and seedling size classes. Mean nearest neighbor distances were 1.29 m, 6.19 m, and 13.29 m for seedling, sapling, and tree size classes, respectively, and were significantly different across size classes as well as between each pair of size classes (Table 2).

Small mammal community

A total of 14 mammal species were captured, sighted, or left sign on the site in 2005; these included herbivores, omnivores, and carnivores ranging widely in size, diet, and behavior (Table 3). Six species of small mammals were captured during the Oct. 2005 survey, including *Peromyscus maniculatus* (Deer mouse), *Reithrodontomys megalotis* (Western harvest mouse), and *Sorex cinereus* (Masked shrew). In the course of the survey, sign of three additional mammal species was observed: *Mephitis mephitis* (Striped skunk), *Odocoileus virginianus* (Whitetailed deer), and *Scalopus aquaticus* (Eastern mole). In addition, five other mammal species were sighted during either the small mammal survey or field research in 2005, including *Vulpes vulpes* (red fox) and *Mustela vison* (American mink).

DISCUSSION

Methodology

Multiple sources of historic information, including a PLS-derived vegetation layer, maps from historic state atlases, interviews with university faculty and staff, and aerial photography from 1939–2004, were utilized to determine the landscape history of the study site. The incorporation of historical data sources other than aerial photography allowed for the development of a more detailed story of landscape change at a broader temporal scale, since settlement of the region by Euro-Americans.

Table 1. Landscape metrics calculated for each time period for which aerial photography was available.

Year	# of Forest Patches	Total Forest Patch Area (m^2)	Mean Forest Patch Area (m^2)	% Tree Canopy	# 0f Grass Patches	Total Grass Patch Area (m^2)	Mean Grass Patch Area(m^2)
1939	19	58917.97	3100.95	62.36	19	35566.82	1871.94
1958	30	47601.20	1586.71	50.38	16	46889.09	2930.57
1980	30	47006.38	1566.88	49.71	13	47559.63	3658.43
2004	3	75299.02	25099.67	79.68	4	19202.44	4800.61

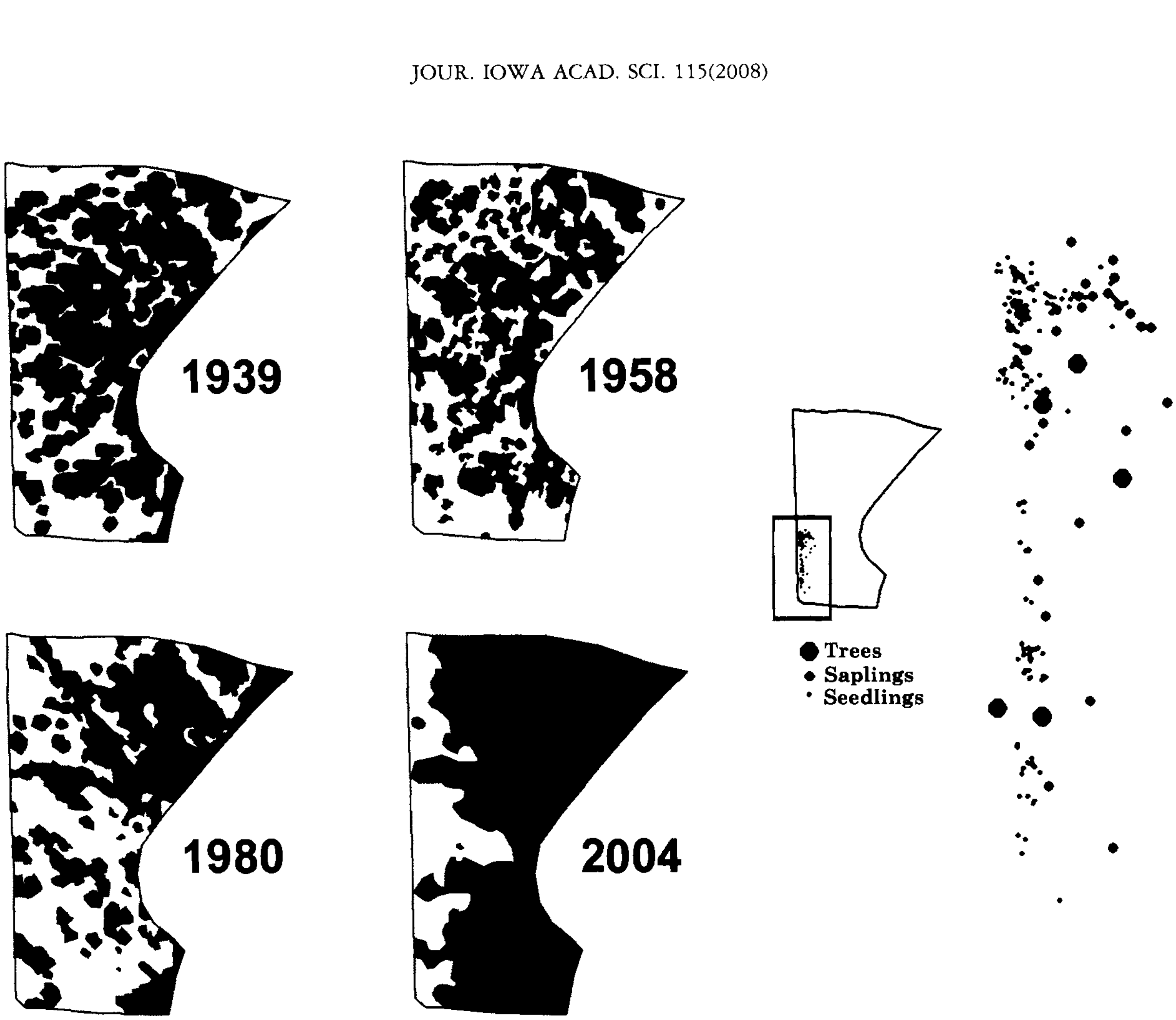

Fig. 3. Digitized land-cover maps of the study site from 1939–2004 (left) and distribution map of bur oaks (seedlings, saplings, trees) located in 2005 (right).

Similar methods were employed by Kettle et al. (2000), who combined data from aerial photography with data derived from various other historical records to develop a land-use history for a prairie-forest ecotone in Kansas. Other authors have highlighted the usefulness of a combination of aerial photography and other historical records specifically for planning the restoration and management of oak savannas (i.e. Apfelbaum and Haney 1991). There are, however, important limitations associated with using most forms of historical data, and vegetation data derived both from PLS survey notes and from both historic state atlases require some qualifications.

In terms of the survey data, PLS-era surveyors recorded the site as being forested – yet there is some ambiguity as to what is meant by the term 'forest.' Significant variation has been noted among surveyors in terms of survey technique and species identification (Schulte and Mladenoff 2001, Whitney and Decant 2001, Bolliger and Mladenoff 2005). However, this study does not compare multiple patches of forest or data acquired by multiple surveyors, so variation between surveyors is of little consequence. Furthermore, the PLS-derived vegetation layer is

Table 2. Mean nearest neighbor distances (m) between trees, saplings and seedlings of bur oak (*Quercus macrocarpa* Michx.) present on the study site in 2005.

Size class	N	Mean NN distance (m)	SE mean
Tree	5	13.3	1.26
Sapling	31	6.2	0.50
Seedling	143	1.3	0.23

Table 3. Combined results of small mammal survey and field observations (sightings and sign) in 2005.

Scientific name	Common name
Blarina brevicauda	Northern short-tailed shrew
Microtus ochrogaster	Prairie vole
Peromyscus leucopus	White-footed mouse
Peromyscus maniculatus	Deer mouse
Reithrodontomys megalotis	Western harvest mouse
Sorex cinereus	Masked shrew
[a]*Sciurus niger*	Fox squirrel
[a]*Sylvilagus floridanus*	Eastern cottontail
[b]*Marmota monax*	Woodchuck
[b]*Mustela vison*	Mink
[b]*Vulpes vulpes*	Red fox
[c]*Mephitis mephitis*	Striped skunk
[c,a]*Odocoileus virginianus*	White-tailed deer
[c]*Scalopus aquaticus*	Eastern mole

[a]species sighted during Oct. 2005 survey
[b]species sighted during 2005 field research
[c]species whose sign was spotted in Oct. 2005 survey

used only to suggest the presence of trees on the site, which is likely no matter how 'forest' was defined by the surveyor. Extraction of specific tree species within the patch of forest that encompassed the study site was precluded by the relatively small size of the site; Delcourt and Delcourt (1997) note that 1 mi^2 is the minimum area at which species data can be reasonably extracted from the survey notes. This is a result of the widely spaced (0.5 mi) survey points at which witness tree species were recorded during the survey (Schulte and Mladenoff 2001).

Data derived from both state atlases are subject to limitations, especially since the exact method of map preparation used is unknown. For example, there is no metadata of any kind associated with the 'timber' map element, and the accuracy associated with the delineation of timber patches is suspect, especially at finer scales. However, timber, forests, and woodlots were important resources to the early Euro-American settlers in Iowa, and their locations were most likely recorded carefully. Furthermore, the time-steps for which atlas maps were used in this study (1875, 1904) were bracketed by time-steps in which trees were found to occur on the site.

Data derived from historic atlases and from the PLS survey notes were used in this study to provide a general description of the on-site vegetation prior to the availability of aerial photography. As with most forms of historical data, there are tradeoffs between temporal resolution, spatial extent, and data quality. In this study, the limitations associated with both historical data sources were accepted, in order to extend the temporal scale of the study to the time of first settlement of the region by Euro-Americans.

GIS analysis of digitized aerial photography helped to elucidate land-cover trends on the site from 1939–2004. The use of relatively general cover classes ("open" prairie and "closed" forest) was appropriate, given the research objectives and observer ability to distinguish landscape features from aerial photos of the site. In future years, aerial photography can be digitized in a similar fashion so that land-cover on the site can be captured and compared to baseline data derived from this research.

Baseline data

The results of this research reveal that there is a flourishing bur oak population present on the study site that we predict will persist in the future as seedlings and saplings mature and replace overstory trees. Analysis of bur oak distribution reveals a pattern that is characteristic of the tree component of native oak savannas; mature, overstory trees were more widely spaced than oak saplings, which in turn were more widely spaced than oak seedlings. Oak seedlings tended to occur some distance from mature oaks (Fig. 3), suggesting either substantial redistribution of acorns by animals or a lack of germination of acorns underneath the shady canopies of larger trees. Seedlings also tended to be highly clumped, relative to saplings and trees. Acorn caching by small mammals is a likely mechanism for this pattern. Alternatively, this result may simply reflect the increased density of seedlings relative to saplings and trees.

The presence of bur oak seedlings and saplings has important implications for the continued restoration of the site, since successful regeneration of oak trees from seedlings is a key component of a successful savanna restoration (Brudvig and Asbjornsen 2005). Saplings may make significant contributions to the annual seed rain of acorns in future years, since some of the mature trees may be past prime seed-bearing age (Deitschmann 1965, Olson 1974) and may produce fewer acorns in years to come. We anticipate that future studies of oaks on the site will find an increased number of oak seedlings, and that oaks will occur on a larger percentage of the total site. As restoration of the site continues, our dataset can be used to evaluate changes in the growth, mortality and distribution of bur oaks across multiple size classes. The evaluation of such changes in the bur oak population could be the subject of a variety of student-led research projects related to forestry and restoration.

Data from the small mammal survey and field observations provide insight as to the composition of the on-site mammal community during early stages of restoration, and can be compared with similar data in the future. Although the degree to which the various mammals present are influencing with-site processes is unclear, both small and large mammals are known to affect prairie and savanna communities through seed predation and dispersal, herbivory, frugivory, and nutrient cycling. In addition, mammals on-site were observed to contribute to micro-site heterogeneity; for example, several burrows of red foxes were observed to create small patches of disturbed soil, which may in turn affect the germination and growth of seeds and seedlings. An additional consideration is interspecific competition between different species of mammals; for example, evidence of small mammal depredation by red foxes was observed during field work in 2005.

The number of small mammal species found on the site during the survey was surprisingly high, given that the study site occurs as a relatively isolated patch in the middle of Ames, a city of over 50,000 people. Although the population dynamics of individual mammal species on the site are unknown, it seems likely that viable populations of mammals are being maintained primarily though within-site processes, and secondarily through immigration from the adjacent riparian corridor and surrounding landscape of parks, neighborhoods, and urban forests.

Landscape history

A key objective of this study was the development of a more detailed landscape history for the study site, in order to better understand the historical plant community and also to illuminate the trajectory of change on the site since the time of settlement of the region by Euro-Americans. This was accomplished through the integration of multiple types of historical data that spanned the time period from ~1840–2004.

Our analysis suggests that the study site has been forested to some degree since at least the early 1800s, given the presence of trees on the site in each of the study time-steps. During that same time span, the majority of the Iowa landscape was converted from native vegetation to agriculture, pasture, housing, and urban land-uses. The adjacency of the site to Squaw Creek, a tributary of the Skunk River (Fig. 1) may explain the persistence of forest vegetation; while over 60% of Iowa woodlands were cleared subsequent to settlement by Euro-Americans, most patches that remained in Iowa and in other Midwestern regions occurred along rivers and streams and in other relatively inaccessible areas (Levenson 1981, Rex and Malanson 1990, Thompson 1992).

Although the presence of trees was noted in each time-step, analysis of aerial photography revealed that significant changes have occurred on-site since 1939. The site has become simpler in terms of the number of discrete patches, and the mean area of both forest and grass present in 2004 was greater than in 1939. These changes occurred primarily from 1980–2004; results from that time period suggest the merging of formerly discrete patches of forest and grass into larger patches. A possible explanation is that periodic livestock grazing on the site from 1940–1989 helped to maintain patch heterogeneity, as there is no evidence of fires on the site prior to the recent introduction of a controlled burning regime. Specifically, grazing by livestock may have contributed to the maintenance of open areas, as well as the persistence of some native species (Johnson et al. 2002). Removal of horses permanently in 1989 (in addition to the continued suppression of fire) most likely allowed for rapid encroachment of shade-tolerant species. Aerial photography from the 1980 and 2004 time-steps reveal a dramatic increase in tree cover on the site during this time period. A similarly rapid time-frame for invasion by woody vegetation in oak savannas has been noted by other authors (Curtis 1959, Wolf 2004). The amount of forest cover present in 2004, however, was most likely less than the amount present in 2000 since the removal of woody vegetation was a key component of early restoration efforts (Pease pers. comm.).

Prior to 1940, no specific land-use could be associated with the site. The estimated age of the present-day, overstory bur oaks suggests that the site was never cleared for agriculture or pasture. The location of the site on a floodplain likely precluded such land-uses, although the site may have instead been part of a woodlot (a common feature in historic Midwestern landscapes) that may or may not have been grazed by cattle (Hewes 1950, Russell 1997).

Evidence of a Remnant Oak Savanna

When restoration activities were initiated in 2000, the large, overstory bur oak trees suggested that the site represented a remnant oak savanna. The results of this research provide additional, but not definitive, evidence in support of this theory. First, the presence of mature, open-grown bur oak trees in Midwestern forests is generally a good indicator that a site was formerly an oak savanna (Nuzzo 1986, McClain et al. 1993, Anderson 1998, Johnson et al. 2002, Wolf 2004). We estimate that the two largest bur oak trees are at least 100 years old, potentially old enough to have been present prior to settlement of the region by Euro-Americans. The site would have likely resembled an oak savanna at that time the trees first sprouted, since bur oaks strongly favor a high light environment for successful seedling recruitment (Rebertus and Burns 1997). Second, the growth forms of the overstory bur oaks on the site (widely spaced individuals, open-grown form, and broadly spreading crowns) strongly resemble descriptions of bur oaks in Midwestern savanna habitats (Anderson 1998). Third, the site contained both herbaceous (native grasses such as *Schizachyrium scoparium* and *Sorghastrum nutans*) and woody vegetation (*Quercus macrocarpa*) associated with many Midwestern oak savannas prior to the initiation of restoration efforts, suggesting that elements of native habitat have persisted over the last 150 years. Ancillary evidence can be drawn from the PLS-derived data and from the atlas maps, both of which indicate the historical presence of trees (although not specifically bur oaks). While not definitive, these lines of evidence suggest that the site represents a remnant bur oak savanna. More detailed plant surveys on-site, as well as in wooded areas adjacent to the site, could potentially reveal additional floristic evidence of site history (e.g, savanna specific plant species). Results from such surveys could be cross referenced with data from existing savanna remnants to assess similarity. In addition, tree coring would allow for a more robust approximation of the age of the mature, overstory bur oaks.

Historically, oak savannas were common through the Midwestern United States (Nuzzo 1986, Fig. 4). The clearing of many savannas for homesites and fields, as well as the suppression of fire by settlers, led to the almost complete loss of this unique habitat type; in Iowa, less than 1% remains (Nuzzo 1986, Wolf 2004). Three types of oak savanna have been identified as being present in Iowa at or near the time of settlement (loess hills savanna, sand savanna, and tallgrass savanna. Loess hills savanna was restricted to the loess hills landform in Western Iowa, and sand savanna was restricted to eastern Iowa. Tallgrass savanna was found throughout the state, often in association with tallgrass prairie, and was dominated by bur oak in conjunction with prairie grasses and a variable herbaceous community (Nuzzo 1986) similar to that present on the study site. Based on this description, we suggest that the site may specifically represent a remnant, tallgrass oak savanna. The location of the site on an active floodplain, however, suggests instead that the site may represent a rare example of floodplain oak savanna. A report characterizing Midwestern oak savannas (Haney and Apfelbaum 1993) describes floodplain oak savannas as occupying floodplains and swales throughout the Upper Midwest, and being dominated by bur oak and swamp white oak (*Quercus bicolor* Willd.), a species not found on the study site.

Education and outreach

In recent years, numerous authors have recognized the potential for restoration activities to enhance student education, especially at the university level (Atkinson 1988, Casagrande 1997, Covington et al. 2000, Schneider 2005). The use of restoration sites as outdoor classrooms allows for "activity-based" learning that has been shown to enhance problem-solving skills and environmental awareness (Hudson 2001), as well as interest in science and mathematics (Casagrande 1997). The educational impact of restoration projects may be higher in landscapes that are more depauperate in terms of native habitat and species (Atkinson 1988), such as those found in the Midwestern United States. Participation in hands-on restoration by university students, coupled with in-class instruction, can lead to enhanced awareness and support among students for conservation and preservation activities (Bowler et al. 1999).

Likewise, education has been recognized as a being an important social component of the practice of ecological restoration (Allen 2003). Students may participate directly in the restoration process, or utilize the site to explore other ecological concepts (such as community composition, changes in landscapes over time, or invasive species). As previously mentioned, the site has already been utilized by a wide variety of students, ranging from age from elementary to post-graduate. In the course of this research, additional students from within the department were directly involved in the collection of field data on the small mammal community. Data from our research were also utilized by a student for a class project that involved the design of a series of interpretive signs for the site, and by another student who designed a poster summarizing the site history. The baseline data derived through this site has been made available to instructors and researchers within the NREM department, the Ecology and Evolutionary Biology Interdepartmental Graduate program, and the Department of Ecology, Evolution, and Organismal Biology at Iowa State University. These data provide numerous starting points for student-led research projects, either as a component of classes or as independent or collaborative studies. For example, the bur oak population may be surveyed again in the future, and changes in the growth, mortality, and distribution of this important savanna species in response to continued restoration efforts could be evaluated. Two in-field lectures regarding site history and ecology were also delivered by

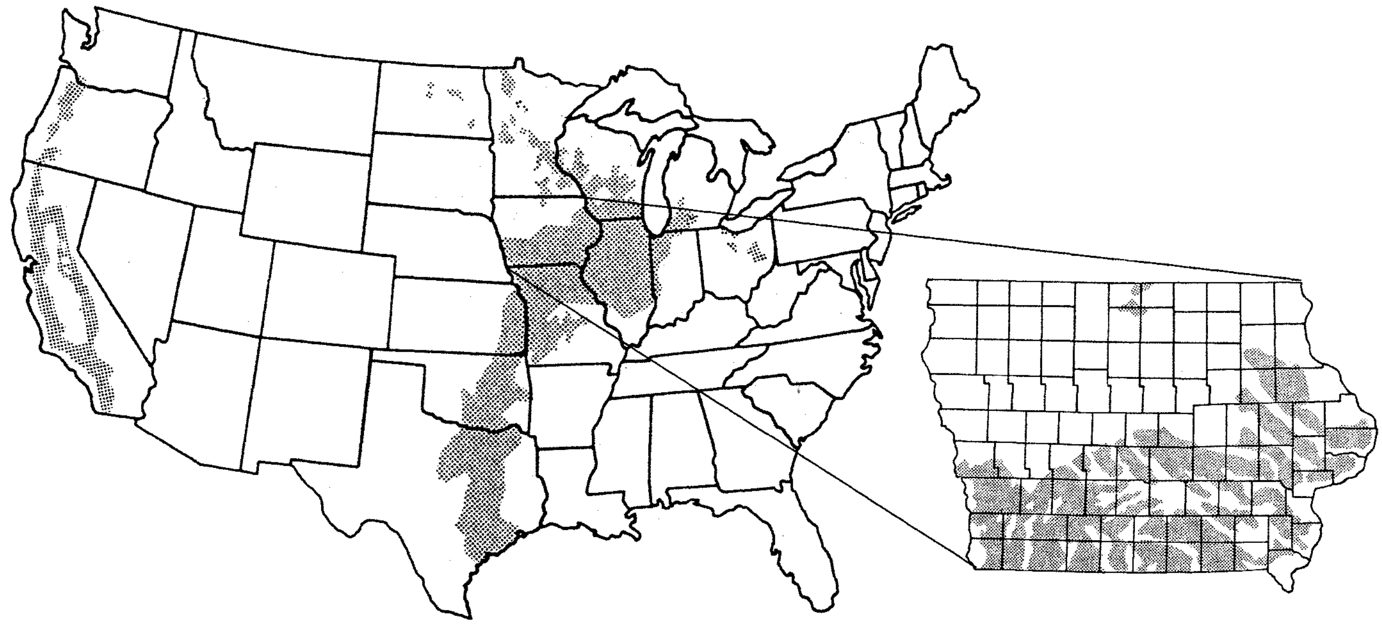

Fig. 4. Approximate pre-settlement distribution of oak savannas in the United States, with detail provided for the state of Iowa. Adapted from Nuzzo (1986).

the authors; one to a mammalogy class (2005), and another to a group of volunteers conducting a controlled burn (2006).

Conclusions

In the course of this research, integrated historical data were used to develop a landscape history for a site in Central Iowa undergoing restoration to a prairie-savanna complex. Baseline data was also collected, in order to assess the effectiveness of restoration efforts and to better understand the present-day state of the floral and faunal communities. Our results suggest that restoration efforts to date have been successful, and that site is on a trajectory towards a state resembling a native oak savanna. Currently the study site is used as more of an ongoing, participatory restoration project, rather than an experimental field site. While the former use is important, especially in urban areas, there are numerous opportunities to conduct both observational and experimental research that examines the response of various ecological factors to ongoing ecological restoration. The data collected in this study may serve as a springboard for future studies of site responses to continued restoration. This in turn would benefit students by providing interesting education experiences outside of the classroom, in addition to opportunities for meaningful research projects.

In its present state, the study site is unique for a variety of reasons. First and foremost, it serves as important habitat for flora and fauna in a state in which the vast majority (>90%) of native habitat has been converted to agricultural and urban land-uses. More specifically, the site is likely a remnant oak savanna, a critically rare habitat type in Iowa and throughout the Midwestern United States. Secondly, the study site is an ideal location for a wide variety of outdoor laboratory and teaching exercises. The site contains numerous ecological elements (such as discrete vegetation layers, urban and forest edges, topological and hydrological variation, and invasive species) that lend themselves to research by undergraduate and graduate students alike. In addition, the site itself is within walking distance of the main campus of Iowa State University, making it easily accessible to students and classes. Lastly, the site is unique because it is nestled within a highly modified urban landscape, rather than being isolated from where people live and work. As such, the site offers the citizens of Ames a critical connection to their natural heritage that is so often lacking within urban environments (Miller 2005).

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